

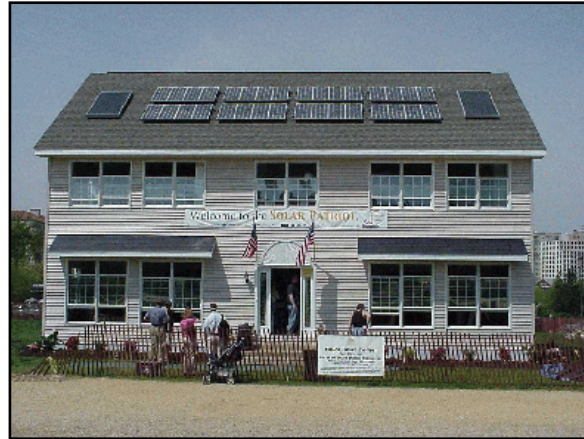
## Solar Buildings

### Technology Description

Solar building technologies deliver heat, electricity, light, hot water, and cooling to residential and commercial buildings. By combining solar thermal and electric building technologies with very energy-efficient construction methods, lighting, and appliances, it is possible to build “Zero Energy Homes” (see photo for a demonstration-home example). Zero Energy Buildings (residential and commercial) have a zero net need for off-site energy on an annual basis and also have no carbon emissions.

#### System Concepts

- In solar heating systems, solar-thermal collectors convert solar energy into heat at the point of use, usually for domestic hot water and space heating.
- In solar cooling systems, solar-thermal collectors convert solar energy into heat for absorption chillers or desiccant regeneration.
- In solar lighting systems, sunlight is transmitted into the interior of buildings using glazed apertures, light pipes, and/or optical fibers.



#### Representative Technologies

- Active solar-heating systems use pumps and controls to circulate a heat transfer fluid between the solar collector(s) and storage. System sizes can range from 1 to 100 kW.
- Passive solar-heating systems do not use pumps and controls but rather rely on natural circulation to transfer heat into storage. System sizes can range from 1 to 10 kW.
- Transpired solar collectors heat ventilation air for industrial and commercial building applications. A transpired collector is a thin sheet of perforated metal that absorbs solar radiation and heats fresh air drawn through its perforations.
- Hybrid solar lighting systems focus concentrated sunlight on optical fibers in order to combine natural daylight with conventional illumination. Hybrid Solar Lighting (HSL) has the potential to more than double the efficiency and affordability of solar energy in commercial buildings by simultaneously separating and using different portions of the solar-energy spectrum for different end-use purposes, i.e. lighting and distributed power generation.

### Technology Applications

- More than 1,000 MW of solar water-heating systems are operating successfully in the United States, generating more than 3 million MW-hrs per year.
- Based on peer-reviewed market penetration estimates, there will be approximately 1 million new solar water-heating systems installed by 2020, offering an energy savings of 0.16 quads (164 trillion Btus).
- Retrofit markets: There are 73 million existing single-family homes in the United States. An estimate of the potential replacement market of 29 million solar water-heating systems assumes that only 40% of these existing homes have suitable orientation and nonshading. (9.2 million replacement electric and gas water heaters.)
- New construction: In 2000, 1.2 million new single-family homes were built in the United States. Assuming 70% of these new homes could be sited to enable proper orientation of solar water-heating systems, this presents another 840,000 possible system installations annually.
- While the ultimate market for the zero-energy building concept is all new building construction; the near-term focus is on residential buildings; particularly, single-family homes in the Sunbelt areas of the

country. Of the 1.2 million new single-family homes built in the United States in 2000, 44% of these new homes were in the southern region of the country and 25% were in the western region, both areas with favorable solar resources.

### Current Status

- About 1.2 million solar water-heating systems have been installed in the United States, mostly in the 1970s and 1980s. Due to relatively low energy prices and other factors, there are approximately only 8,000 installations per year.
- Typical residential solar systems use glazed flat-plate collectors combined with storage tanks to provide 40% to 70% of residential water-heating requirements. Typical systems generate 2500 kWh of energy per year and cost \$1 to \$2/Watt, or 8¢/kWh.
- The energy costs of solar thermal systems have declined by more than 50% due to technology improvements. This cost reduction has saved more than five million MWh/year in U.S. primary energy consumption.
- Typical solar pool-heating systems use unglazed polymer collectors to provide 50% to 100% of residential pool-heating requirements. Typical systems generate 1,600 therms or 46,000 kWh of energy per year and cost \$0.30 to \$0.50/Watt
- Four multidisciplinary homebuilding teams have begun the initial phase of designing and constructing “Zero Energy Homes” for various new construction markets in the United States. Several homebuilders have started building houses with Zero Energy Home features—solar electric systems, solar water heating, and energy-efficient construction.
- Key companies developing or selling solar water heaters include:

Alternative Energy Technologies  
 Aquatherm  
 FAFCO  
 Radco Products  
 Sun Systems

Harter Industries  
 Duke Solar  
 Heliodyne, Inc.  
 Sun Earth  
 Thermal Conversion Technologies

### Technology History

- 1890s- First commercially available solar water heaters produced in southern California. Initial designs were roof-mounted tanks and later glazed tubular solar collectors in thermosiphon configuration. Several thousand systems were sold to homeowners.
- 1900s- Solar water-heating technology advanced to roughly its present design in 1908 when William J. Bailey of the Carnegie Steel Company, invented a collector with an insulated box and copper coils.
- 1940s- Bailey sold 4,000 units by the end of WWI, and a Florida businessperson who bought the patent rights sold nearly 60,000 units by 1941.
- 1950s- Industry virtually expires due to inability to compete against cheap and available natural gas and electric service.
- 1970s- The modern solar industry began in response to the OPEC oil embargo in 1973-74, with a number of federal and state incentives established to promote solar energy. President Jimmy Carter put solar water-heating panels on the White House. FAFCO, a California company specializing in solar pool heating; and Solaron, a Colorado company that specialized in solar space and water heating, became the first national solar manufacturers in the United States. In 1974, more than 20 companies started production of flat-plate solar collectors, most using active systems with antifreeze capabilities. Sales in 1979 were estimated at 50,000 systems. In Israel, Japan, and Australia, commercial markets and manufacturing had developed with fairly widespread use.
- 1980s- In 1980, the Solar Rating and Certification Corp (SRCC) was established for testing and certification of solar equipment to meet set standards. In 1984, the year before solar tax credits expired,

an estimated 100,000-plus solar hot-water systems were sold. Incentives from the 1970s helped create the 150-business manufacturing industry for solar systems with more than \$800 million in annual sales by 1985. When the tax credits expired in 1985, the industry declined significantly. During the Gulf War, sales again increased by about 10% to 20% to its peak level, more than 11,000 square feet per year (sq.ft./yr) in 1989 and 1990.

- 1990s- Solar water-heating collector manufacturing activity declined slightly, but has hovered around 6,000 to 8,000 sq.ft./yr. Today's industry represents the few strong survivors: More than 1.2 million buildings in the United States have solar water-heating systems, and 250,000 solar-heated swimming pools exist. Unglazed, low-temperature solar water heaters for swimming pools have been a real success story, with more than a doubling of growth in square footage of collectors shipped from 1995 to 2001.

Reference: American Solar Energy Society and Solar Energy Industry Association

### Technology Future

- Near-term solar heating and cooling RD&D goals are to reduce the costs of solar water-heating systems to 4¢/kWh from their current cost of 8¢/kWh using polymer materials and manufacturing enhancements. This corresponds to a 50% reduction in capital cost.
- Near-term Zero Energy Building RD&D goals are to reduce the annual energy bill for an average-size home by 50% to \$600 by 2004 and to \$0 by 2020.
- Near-term solar lighting RD&D goals are to reduce the costs of solar lighting systems to 5¢/kWh.
- Zero-energy building RD&D efforts are targeted to optimize various energy efficiency and renewable energy combinations, integrate solar technologies into building materials and the building envelope, and incorporate solar technologies into building codes and standards.
- Solar heating and cooling RD&D efforts are targeted to reduce manufacturing and installation costs, improve durability and lifetime, and provide advanced designs for system integration. The RD&D goal by 2025 is to research, develop, and demonstrate marketable and advanced energy systems needed to achieve “net-zero” energy use in new residential and commercial buildings. To achieve this, a 70% reduction in building energy use is needed; this can be achieved through high-performance lighting, HVAC, and appliances. The balance of the energy requirements will be met by renewable energy sources.

**Source:** National Renewable Energy Laboratory. *U.S. Climate Change Technology Program. Technology Options: For the Near and Long Term.* DOE/PI-0002. November 2003.

## Solar Buildings

### Market Data

U.S. Installations  
(Thousands of Sq. Ft.)

Source: EIA, *Renewable Energy Annual 2003* Table 18 and Table 10, REA 2002 Table 18, REA 1997- 2000 Table 16, REA 1996 Table 18

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003
Annual												
DHW				755	765	595	463	373	367	274	423	511
Pool Heaters				6,763	6,787	7,528	7,201	8,141	7,863	10,797	11,073	10,800
Total Solar Thermal 1	18,283	19,166	11,164	7,136	7,162	7,759	7,396	8,046	7,857	10,349	11,004	10,926

Cumulative

DHW												
Pool Heaters												
Total Solar Thermal 1	62,829	153,035	199,459	233,386	240,548	248,307	255,703	263,749	271,606	281,955	292,959	303,885

9 1. Domestic shipments - total shipments minus export shipments

U.S. Annual Shipments  
(Thousand Sq. Ft.)

Source: EIA, *Renewable Energy Annual 2003* Table 11 and REA 1999 Table 11.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	19,398	N/A	11,409	7,666	7,616	8,138	7,756	8,583	8,354	11,189	11,663	11,444
Imports		N/A	1,562	2,037	1,930	2,102	2,206	2,352	2,201	3,502	3,068	2,986
Exports	1,115	N/A	245	530	454	379	360	537	496	840	659	518

U.S. Shipments by Cell  
Type (thousands of sq. ft.)

Source: EIA *Annual Energy Review 2003* Table 10.3 and *Renewable Energy Annual 2003* Table 12.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003
Low-Temperature Collectors	12,233	N/A	3,645	6,813	6,821	7,524	7,292	8,152	7,948	10,919	11,126	10,877
Medium-Temperature Collectors	7,165	N/A	2,527	840	785	606	443	427	400	268	535	560

High-Temperature Collectors	N/A	N/A	5,237	13	10	7	21	4	5	2	2	7
Total	19,398	N/A	11,409	7,666	7,616	8,137	7,756	8,583	8,353	11,189	11,661	11,444
1985 values not available.												

U.S. Shipments of High Temperature Collectors by Market Sector, and End Use (Thousands of Sq. Ft.)

Source: EIA, *Renewable Energy Annual 2003* Table 18, REA 2002 Table 18, REA 1996 Table F9, REA 1997, 1999-2000 Table 16, and REA 1998 Table 19.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003
<b>Market Sector</b>												
Residential				0	0	0	0	0		0	0	0
Commercial				1	7	7	18	0		1	2	7
Industrial				0	2	0	0	0		0	0	0
Utility				9	0	0	2	4		1	0	0
Other				3	0	0	1	0		0	0	0
Total				13	10	7	21	4		2	2	7
<b>End Use</b>												
Pool Heating				0	0	0	0	0		0	0	0
Hot Water				0	7	7	18	0		0	0	0
Space Heating				0	0	0	0	0		0	0	0
Space Cooling				1	0	0	0	0		0	0	0
Combined Space and Water Heating				0	0	0	0	0		0	2	7
Process Heating				0	2	0	0	0		0	0	0
Electricity Generation				9	0	0	2	4		2	0	0
Other				2	0	0	1	0		0	0	0
Total				13	10	7	21	4		2	2	7

2000 data not published by EIA

U.S. Shipments of Medium-Temperature Collectors by Market Sector, and End Use (Thousands of Sq. Ft.)

Source: EIA, *Renewable Energy Annual 2003* Table 18, REA 2002 Table 18, REA 1996 Table F9, REA 1997, 1999-2000 Table 16, and REA 1998 Table 19.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003
<b>Market Sector</b>												
Residential				774	728	569	355	366		238	481	507
Commercial				51	50	35	70	59		23	69	44
Industrial				12	1	0	18	0		5	60	0
Utility				0	0	0	0	0		0	4	0
Other				3	7	2	0	2		1	1	2
Total				839	786	606	443	426		268	614	553
<b>End Use</b>												
Pool Heating				32	21	11	36	12		16	28	22
Hot Water				743	754	588	384	373		231	421	510
Space Heating				62	6	2	13	24		9	145	4
Space Cooling				0	0	0	0	0		0	0	0
Combined Space and Water Heating				2	2	3	8	16		12	15	16
Process Heating				0	1	0	0	0		0	4	0
Electricity Generation				0	0	0	0	0		0	0	0
Other				0	0	1	1	2		0	0	0
Total				839	784	605	442	427		268	614	553

2000 data not published by EIA

U.S. Shipments of Low-Temperature Collectors by Market Sector, and End Use (Thousands of Sq. Ft.)

Source: EIA, *Renewable Energy Annual 2003* Table 18, REA 2002 Table 18, REA 1996 Table F9, REA 1997, 1999-2000 Table 16, and REA 1998 Table 19.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2002
<b>Market Sector</b>												
Residential				6,192	6,146	6,791	6,810	7,408		9,885	10,519	9,993

Commercial	552	625	726	429	726	987	524	813
Industrial	69	51	7	44	18	12	2	71
Utility	0	0	0	0	0	0	0	0
Other	0	0	0	2	0	34	0	0
Total	6,813	6,822	7,524	7,285	8,152	10,919	11,046	10,877
End Use								
Pool Heating	6,731	6,766	7,517	7,164	8,129	10,782	11,045	10,778
Hot Water	11	4	0	60	0	42	1	0
Space Heating	70	51	7	53	18	61	0	65
Space Cooling	0	0	0	0	0	0	0	0
Combined Space and Water Heating	*	0	0	8	0	0	0	0
Process Heating	0	0	0	0	5	34	0	34
Electricity Generation	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0
Total	6,813	6,821	7,524	7,285	8,152	10,919	11,046	10,877

2000 data not published by EIA

## Technology Performance

	Source: Arthur D. Little, <i>Review of FY 2001 Office of Power Technology's Solar Buildings Program Planning Unit Summary</i> , December 1999.								
Energy Production	1980	1985	1990	1995	2000	2005	2010	2015	2020
Energy Savings									
DHW (kWh/yr)					2,750				
Pool Heater (therms/yr)					1,600				

Cost	Source: Hot-Water Heater data from Arthur D. Little, <i>Water-Heating Situation Analysis</i> , November 1996, page 53, and Pool-Heater data from Ken Sheinkopf, <i>Solar Today</i> , Nov/Dec 1997, pp. 22-25.								
	1980	1985	1990	1995	2000	2005	2010	2015	2020
Capital Cost* (\$/System)									
Domestic Hot-Water Heater					1,900 - 2,500				
Pool Heater					3,300 - 4,000				
O&M (\$/System-yr)									
Domestic Hot-Water Heater					25 - 30				
Pool Heater					0				

\* Costs represent a range of technologies, with the lower bounds representing advanced technologies, such as a low-cost polymer integral collector for domestic hot-water heaters, which are expected to become commercially available after 2010.